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(NASA-CR-150711) MOBILE BAY TURBIDITY STUDY
Final Report, 1 Apr. 1976 - 31 Sep. 1977
(Marine Environmental Sciences Consortium)
60 p HC A04/MF A01 CSCI 08J

N78-25506

Unclas
G3/43 21584

FINAL REPORT

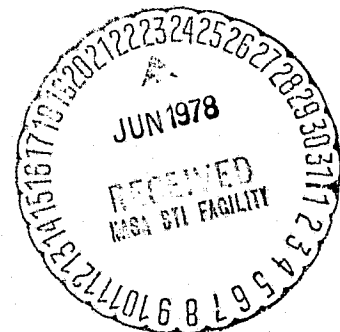
MOBILE BAY TURBIDITY STUDY
April 1, 1976 - September 31, 1977

Submitted: May, 1978

NAS8-30810

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INTRODUCTION

This report covers the termination of studies carried on for almost three years in the Mobile Bay area and adjacent continental shelf. The initial results concentrating on the shelf and lower bay were presented in the interim report submitted in April of 1976.

The continued scope of work was designed to attempt a refinement of the mathematical model, assess the effectiveness of optical measurement of suspended particulate material and disseminate the acquired information.

The data input to the mathematical model was presented in the final report on contract number NAS8-29100 by Dr. Gary April. It was the original goal to meld the sea-truth data, mathematical model and remotely-sensed imagery into a coherent data management package which could be massaged within the technical facilities at Marshall Space Flight Center.

PROBLEMS

The principal difficulties lay in two disparate areas, one highly technical and the other highly pragmatic. The more obvious of the two was the predictable difficulty in getting images, boats and people, instruments, and weather all functioning simultaneously. This problem remains unsolved and probably will maintain that unpleasant status for some time.

The other problem is more subtle but no less frustrating. The optical characteristics of particulate solutions are affected by density gradients within the medium, density of the suspended particles, particle size, particle shape, particle quality, albedo, and the angle of refracted light. Several of these will be discussed in detail below.

ACCOMPLISHMENTS

- 1) The influence of pycnocline intensity on transmissivity was clearly and quantitatively established.
- 2) The driving forces of "turbidity" in Mobile Bay have been identified and described qualitatively.
- 3) The limitations and potential use of transmissivity (%T) vs. suspended particulate material density (mg/l) plots have been defined.
- 4) The value of remotely sensed imagery in describing estuarine processes has been clearly established.

RESULTS

1. Optical properties: In order to generate the required data base an early decision was made to utilize the method of transmissometry. This effectively measures the light transmitted at 180° from a source across a known path length. Obviously the higher the suspended particulate material (SPM) load, the less light, as percent transmission (%T), will reach the sensor. It was established that a defined standard particulate material i.e. kaolin, could give a reproducible calibration curve which would permit the conversion of percent transmission (%T) values to "optical density (mg/l)". (Figure 1). Unfortunately this system does not allow for the vagaries of particle density and shape. It is clearly obvious that dynamic processes in the Bay system do effectively sort the sediments and definable depositional patterns therefore emerge (Ryan, 1969). An assumption of particle uniformity was never considered valid but the hypothesis of possible utility for the concept of "optical mg/l" was tested in the current phase. The results in Figure 2 indicate

Figure 1. Calibration curve of Hydro Products 612S
transmissometer utilizing a 10 cm path length
and preweighed amounts of Kaolin.

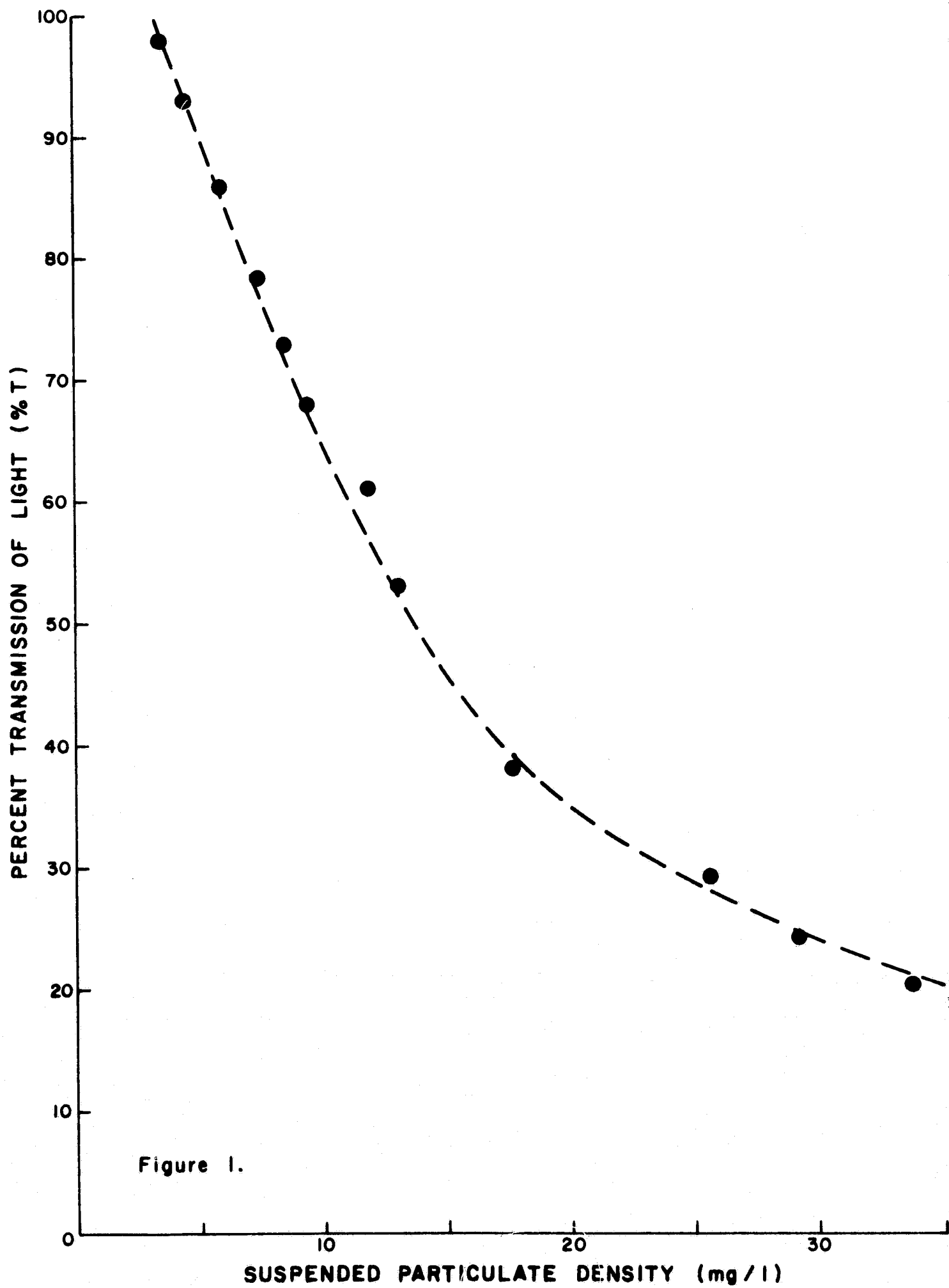


Figure 2. Composite of all field data. Dashed line
represents laboratory generated Kaolin curve.

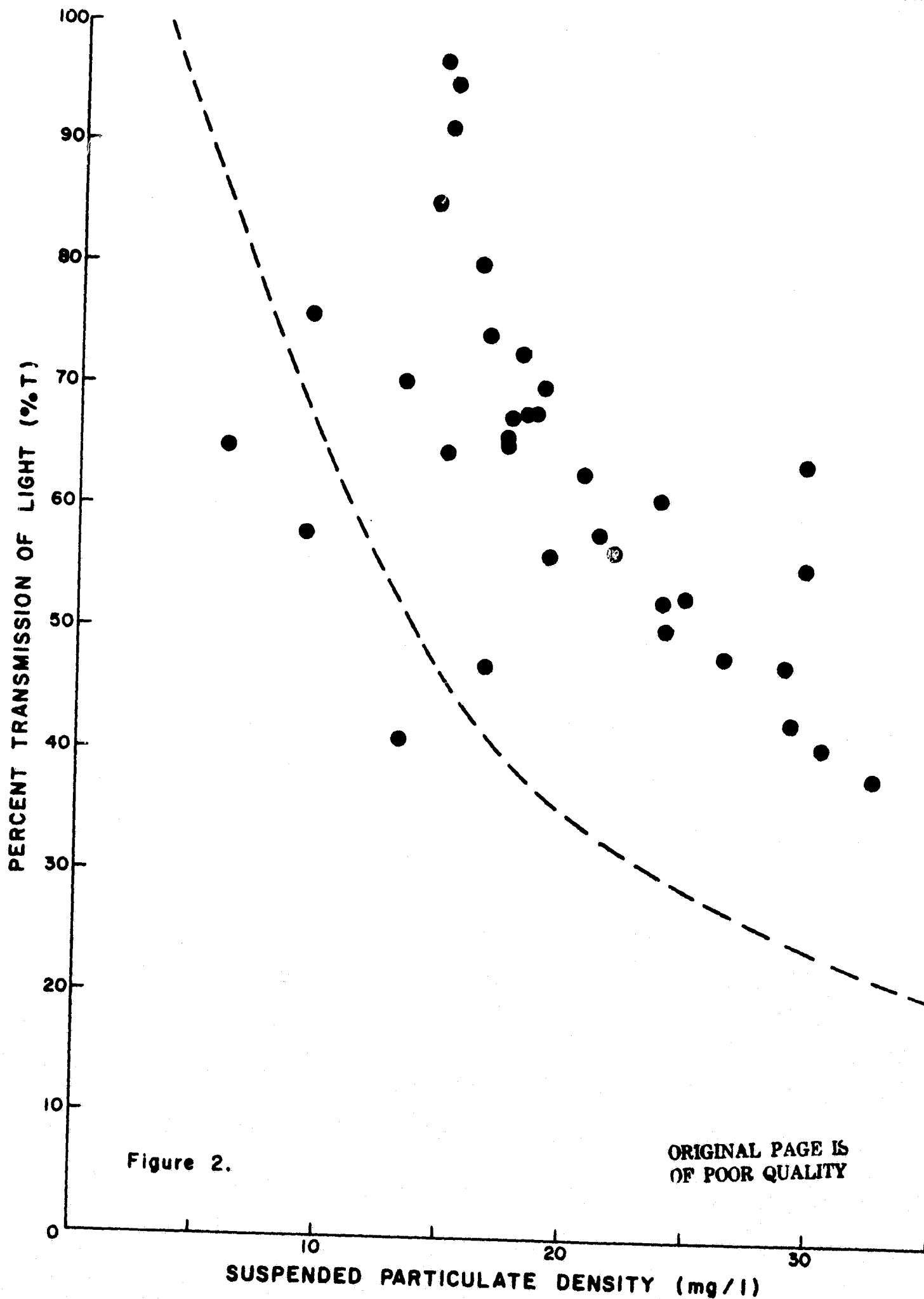


Figure 2.

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that the use of a standard reference material is probably not satisfactory under most conditions. Thus gross scanning of the Bay system via density - slicing and color assignments cannot yet be based on optical characteristics of transmissivity. There are more accurate systems (see appendix A) but these are relatively slow, expensive and less readily adaptable to small boat operations. All of which are detrimental to a pragmatic, management - oriented program.

On the other hand, there is an extremely intriguing clustering of points on the %T - mg/l plots (Figure 3,4,5 and 6) which may be attributed to the natural sorting process. This may constitute a virtual "fingerprint" of sediment type which could conceivably be used to map the movement of sediment deposits within the Bay. In view of the constant maintenance dredging and projected construction within Mobile Bay, this could emerge as a major tool, particularly in combination with remote images.

In theory this is reminiscent of the use of Mie theory by Burt (1955) in Chesapeake Bay. Both analytical exercises take advantage of the unique and complex interaction of particle characteristics with light. Burt was optically able to document changing particle size and the procedure has been confirmed for Mobile Bay (George F. Crozier, unpublished data). There have been no acceptable geochemical "tags" identified for these recent sediment deposits so an optical/gravimetric parameter could be a major breakthrough in small scale sediment transport studies.

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Figure 3. Field data (solid line) collected on the Dauphin Island Bridge during the period July through September, 1977. Dashed line represents laboratory generated Kaolin curve.

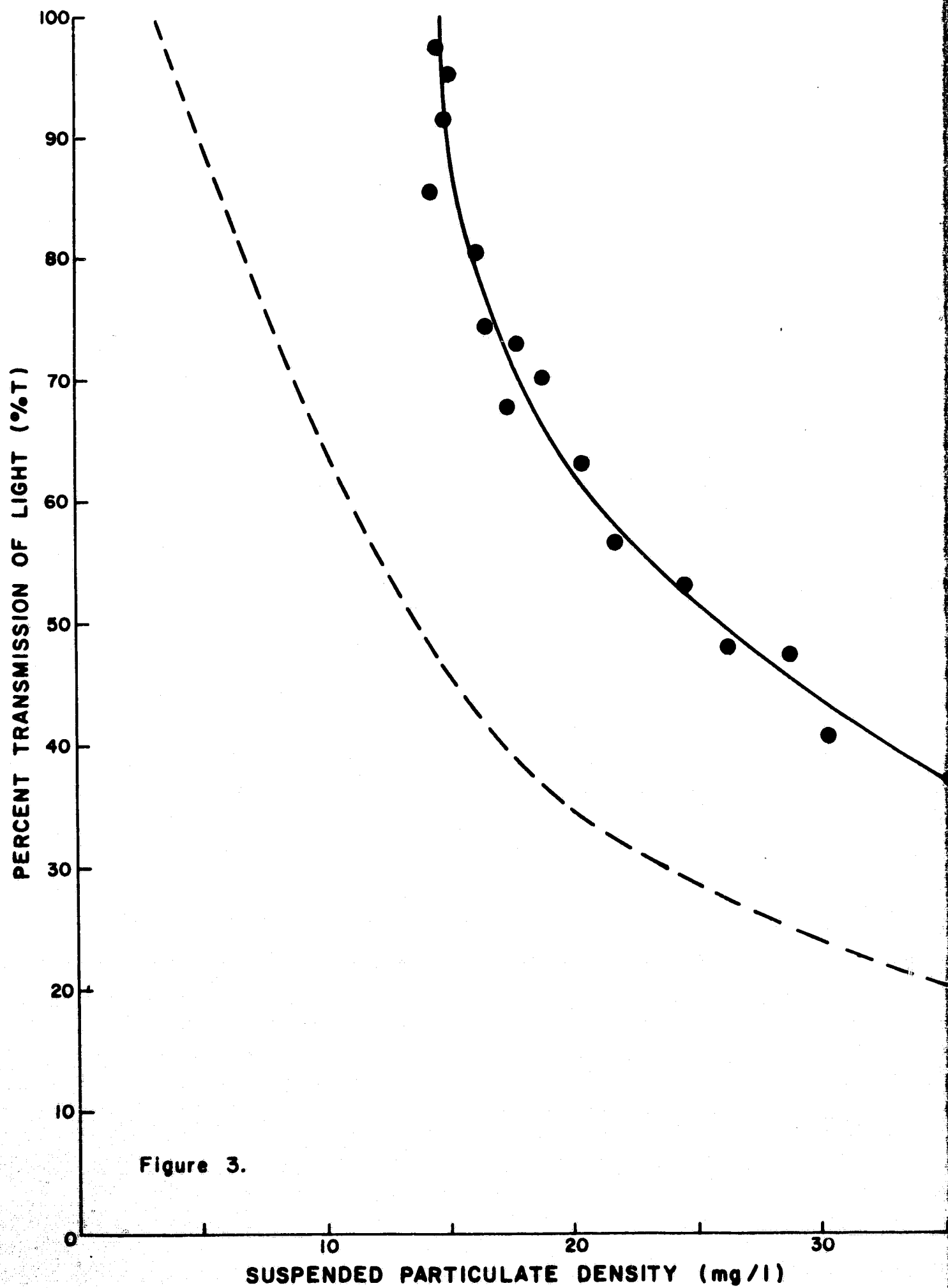


Figure 3.

Figure 4. Field data (solid line) collected on East End Pier of Dauphin Island during the period August, 1976 through September, 1977. Dashed line represents laboratory generated Kaolin curve.

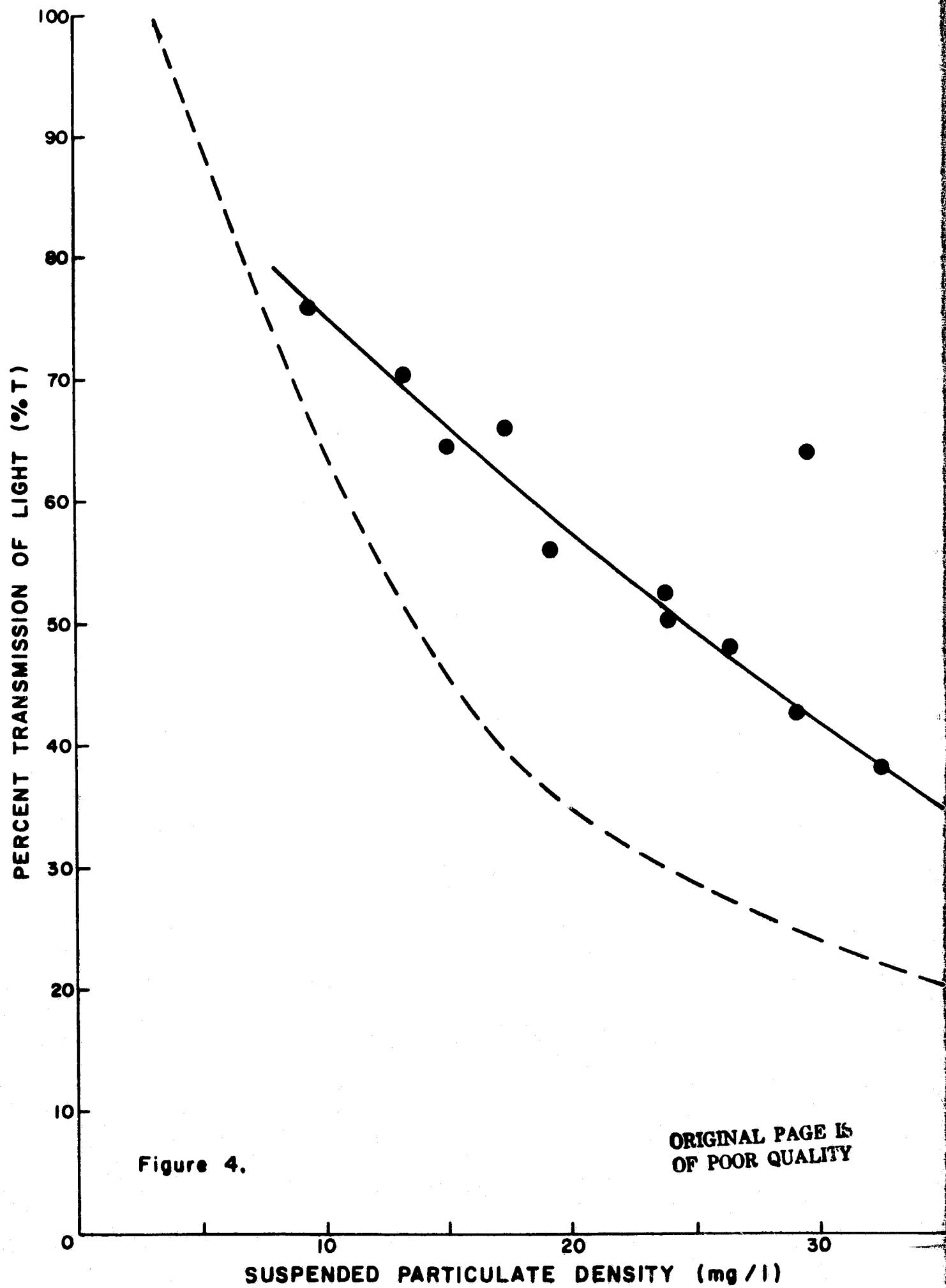


Figure 5. Field data (individual points) collected at six stations in central and lower western Mobile Bay on September 8, 1977. Dashed line represents laboratory generated Kaolin curve.

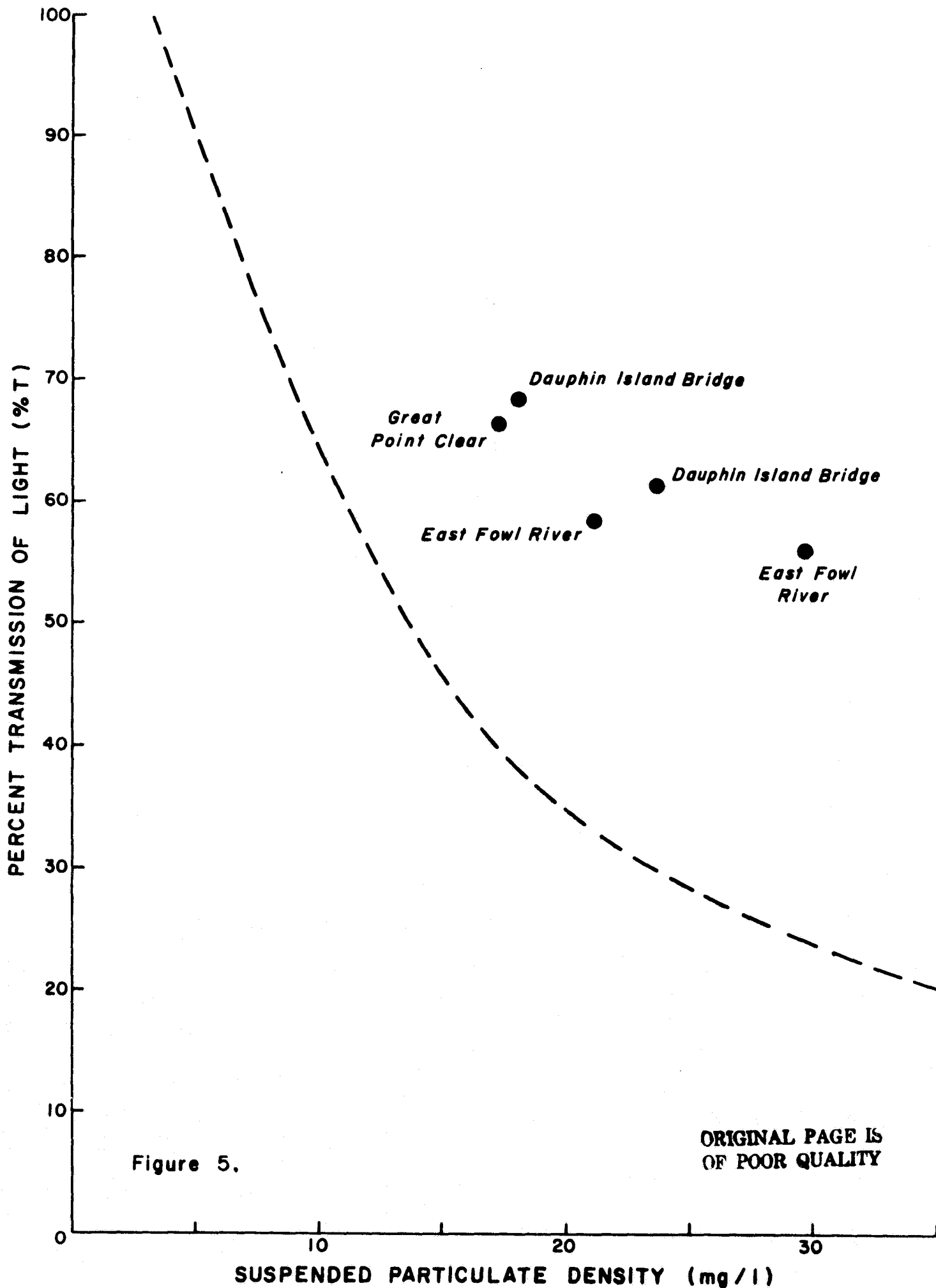
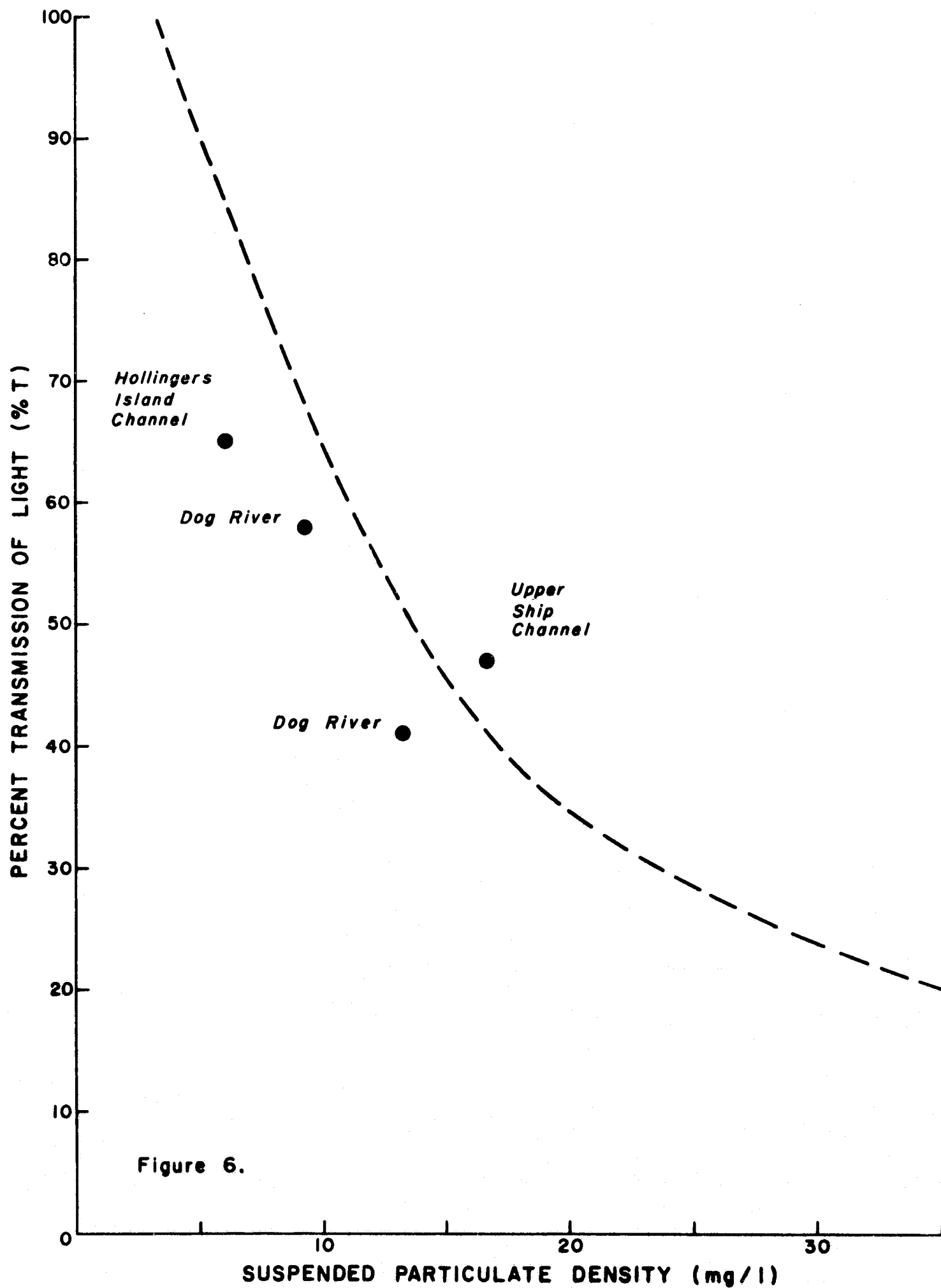


Figure 5.

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Figure 6. Field data (individual points) collected at four stations in upper Mobile Bay on September 16, 1977. Dashed line represents laboratory generated Kaolin curve.



2. Driving Forces: The multi-faceted nature of the problem was recognized during the earlier stages of this study. However, this awareness did not, in the opinions of the investigators, preclude at that time the possibility of achieving a 1st or 2nd order understanding of each of these "driving forces". It wasn't until the majority of the data, primarily macro-and meso-scale descriptive data had been collected that it became apparent that micro-scale knowledge of the structure and spatial-temporal behavior of the individual "driving forces" would be required before any break down of the components of data sets could take place. This "filtering" step would have allowed selected phenomena (e.g. driving forces) to be identified and isolated. Had this been achieved a 1st order SPM (turbidity) budget could have been constructed. The current research has produced field data sets capable of developing SPM & hydro-graphic distributional patterns that are a function of at least two driving forcing but the effect of one cannot be distinguished from the other. Table 1 summarizes all of the field surveys conducted for NASA under contract NAS8-30810 during the period 4/1/76 to 9/31/77. The majority of these surveys do not contribute any significant input towards understanding the SPM budget or related processes. Those surveys that can play a role in this report are included in Table 2. Table 2 includes information about selected environmental conditions that prevailed during the surveys, and which previously established as having significant input on the SPM load. Table 3 lists the available LandSat imagery during the contract period 8/6/76 to 9/23/77. Note that only on five occasions were both an image and sea truth data available on the same date and, of those,

TABLE 1. Summary of field surveys conducted for NASA contract NAS8-30810
during the period 4/1/76 to 9/31/77.

1. Dauphin Island East End Pier.

August (76) 6, 10, 11, 12, 13, and 16
October (76) 14 and 21
November (76) 8, 9, 10, 11 and 12
January (77) 27 and 28
February (77) 10, 15, 18, 23 and 28
July (77) 18, 21 and 29
August (77) 18
September (77) 7, 8 and 19

2. Main Pass Standard Transect

August (76) 12, 16 and 18
September (76) 17, 20 and 24
November (76) 10
January (77) 20
September (77) 2

3. Dauphin Island Bridge (Grants Pass)

July (77) 19 and 30
August (77) 2, 24, 25 and 30
September (77) 5, 7 and 15

4. East Main Pass Anchor Station

September (76) 29

5. Lower Mobile Bay Drogue Release

November (76) 9

6. Lower Mobile Bay Surveys

August (76) 6 and 18
October (76) 19
July (77) 1
August (77) 18

7. Upper Mobile Bay Surveys

August (76) 18
October (76) 19
September (77) 8, 16 and 23

8. Inner Continental Shelf Surveys

August (76) 17
November (76) 4 (Anderson Reef)

TABLE 2. Selected field surveys with their associated environmental conditions.

DATE	LOCATION	RIVER DISCHARGE	WIND @ OBSERVATION	WIND PRE- 24 HRS.	TIDAL HEIGHTS DIFFERENCES *
9/29/76	East Main Pass	Low	Variable	Variable	.5m
11/8-12/76	Dauphin Island East End Pier	Low	See Figure 2	N/A	.3 to .4m
1/20/77	Main Pass	High	West/10 kts	NNW/10-18 kts	.5m

* Calculated from the 1976 & 1977 NOAA/NOS Tide Table.

TABLE 3. Landsat imagery available during the contract dates.
August 6, 1976 to September 23, 1977.

DATE	SAT	%CC	USUABLE	DATE	SAT	%CC	USUABLE	DATE	SAT	%CC	USUABLE
*8/12	B	20	Y	1/30	A			7/20	B	70	N
8/21	A	20	Y	2/08	B	10	Y	7/26	A		
8/30	B	10	Y	2/14	A	0	Y	8/07	B	20	?
9/08	A			2/26	B	10	Y	8/13	A		
*9/17	B	30	N	3/04	A			*8/25	B	70	N
9/26	A			3/16	B	70	N	8/31	A		
10/05	B	30	Y	3/22	A			9/12	B	?	?
*10/14	A	10	Y	4/03	B	50	N	9/18	A		
10/23	B	10	Y	4/09	A	10	Y				
11/01	A			4/21	B	90	N				
*11/10	B	70	N	4/27	A						
11/19	A			5/09	B	10	Y				
11/28	B	90	N	5/15	A	10	Y				
12/07	A			5/27	B	10	Y				
12/16	B	12	N	6/02	A	10	Y				
12/25	A			6/14	B	50	N				
1/03	B	90	N	6/20	A	40	N				
1/12	A			7/02	B	10	N				
1/21	B	0	Y	7/08	A	10	Y				

* Both image and sea truth data available on the same date.

Y - Yes

N - NO

only two of the images were useable (cloud cover precluded the use of the other three images). A discussion of the relationship between SPM distributional patterns and the three principal driving forces utilizing three of the field surveys will serve to illustrate the complexity of the problem. The study area is presented in Figure 7.

CASE 1. Date - 9/29/76
Location - East Main Pass, Mobile Bay
River Discharge - Low
Winds - Variable
Tidal Height differences - .3 - .4 m (moderate to large)

Case 1 is the only case where one of the three driving forces dominates. Tidal height differences during the survey were moderate to large while river discharge was low and winds were variable. A time series section at East Main Pass is illustrated in Figure 8. Two low light transmission areas were observed at the water-sediment interface. Because there was no wind-wave action it is strongly suggested that bottom tidal currents are responsible for these features. Supporting this contention is the fact that peak ebbing tidal currents of 2.0 kts were predicted to occur around 0850 hours. An explanation for the trend of decreasing light transimssion in the upper water column towards the end of the time series is not apparent. A simple suggestion is that advective processes moved SPM, that had been resuspended by either wind-wave action in a shallower portion of the bay or tidal currents, into the Main Pass area.

CASE 2. Date - 11/8-12/76
Location - Dauphin Island East End Pier
River Discharge - Low
Winds - See Figure 2
Tidal Height differences - .5m (large)

Figure 9 illustrates a time series section from a single sampling location on the Dauphin Island East End Pier. The lowest light transmission is evident in the lower left where values of less than 20% transmission where

Figure 7. The study area.

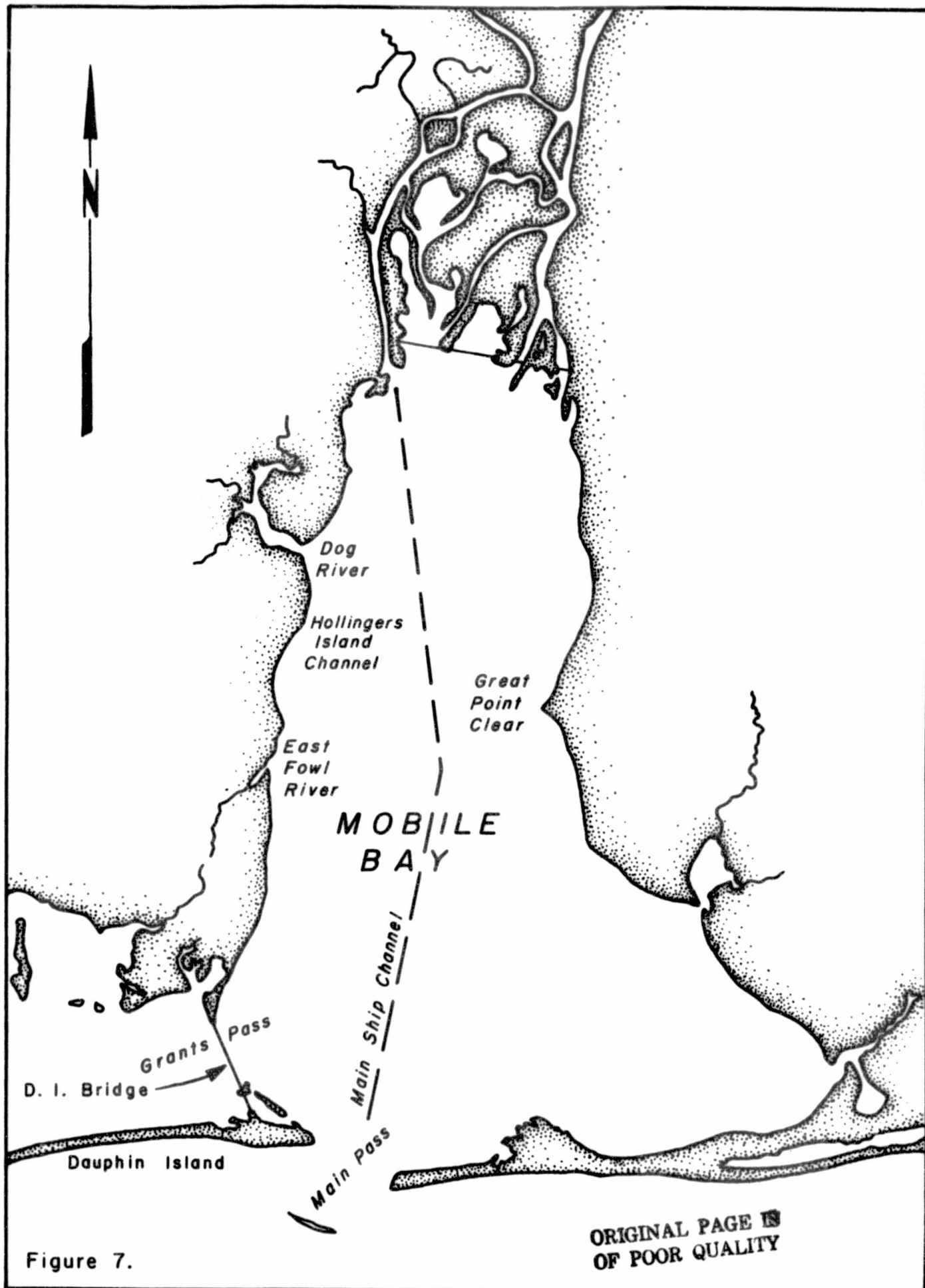


Figure 8. Time series section of transmissivity (%T) at
East Main Pass, Mobile Bay, September 29, 1976.

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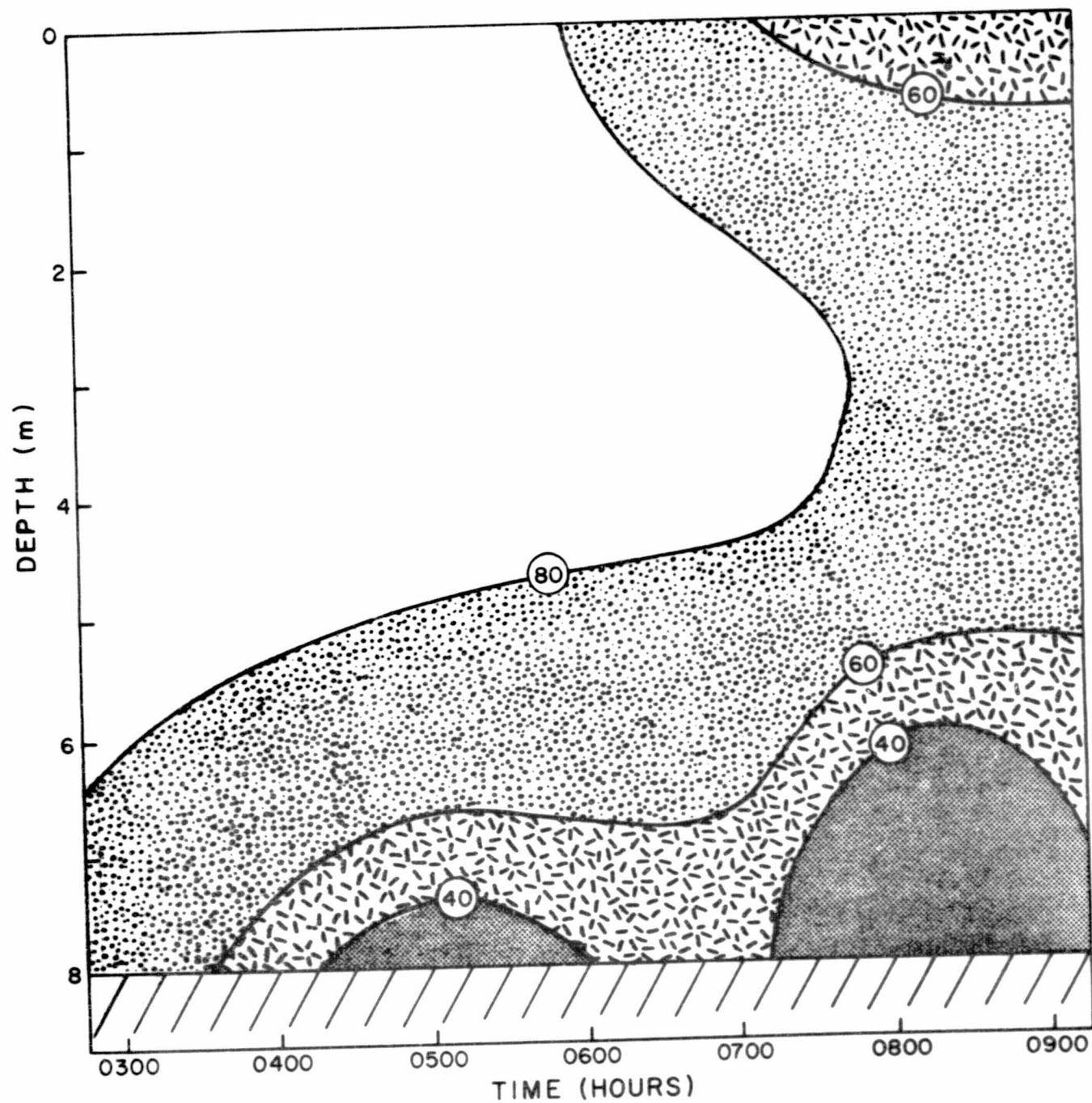


Figure 8.

Figure 9. Time series section of transmissivity (%T)
at the East End Pier of Dauphin Island,
November 8-12, 1976.

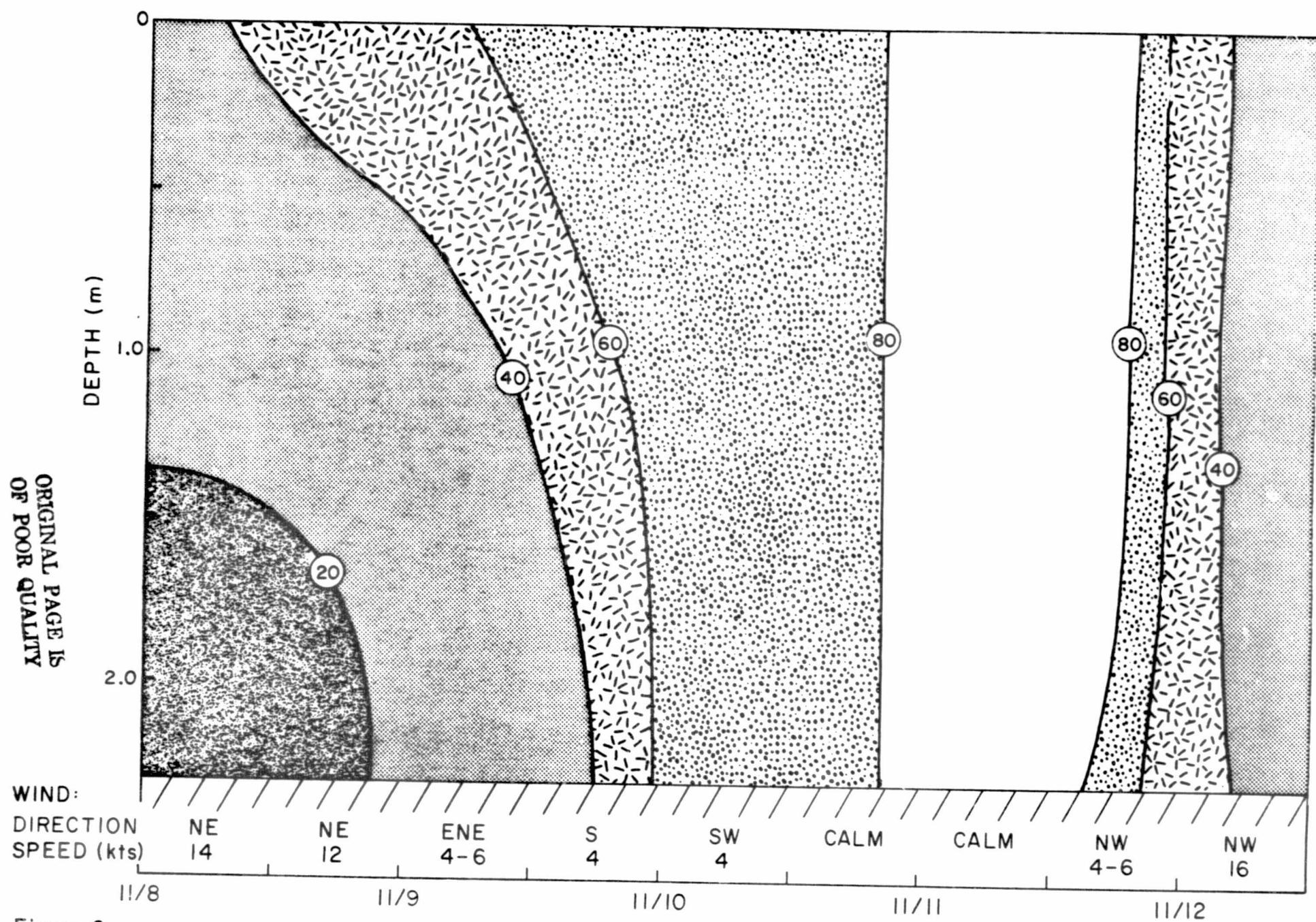


Figure 9.

where measured. At the same time towards the surface in the water column higher light transmissions are found. Winds 12 hours prior to the first measurement were generally variable between 2 to 6 knots. The 20 percent transmission was observed during winds of 12-14 kts from the NE. As the wind speeds diminished and the direction changed the percent transmission increased, as a function of less wave action resulting in SPM settling out. It is possible that moderate tidal currents may have played a role because both wave action and bottom tidal currents would have resuspended sediment in a similar fashion but there is no way in this case of separating wind and tidal effects. Reinforcing the evidence supporting the wind as the main driving force for this case is the end of the time series where the percent light transmission decreased (SPM increases) with an increase in the wind.

CASE 3. Date 1/20/77
Location Main Pass, Mobile Bay
River Discharge - High
Wind - NNW to W/10-18 kts
Tidal Height Differences - .5 (large)

~~FIGURE 10~~ PAGE BLANK NOT PLACED

At first glance it would appear that this case has a well defined single driving force, the high river discharge. A surface layer consisting of large quantities of SPM, indicated by transmissometry values $< 20\%$, transported by river or very low salinity waters (Figure 10). Supportive data include Figure 11 which is a Landsat image of coastal Alabama made the following day, 1/21/77. This image definitely links the SPM in the lower Bay with the river system to the north.

The difficulty in using this case as an example for illustrating the role of river discharge in the SPM budget is that the effect of wind-wave resuspension, brought about by the concurrent high winds, can not be overlooked as an input source. The task of determining the individual roles played by these two driving forces is virtually impossible at this

Figure 10. Transmissivity (%T) cross section, running
west (left) to east (right) across Main Pass,
Mobile Bay, January 20, 1977.

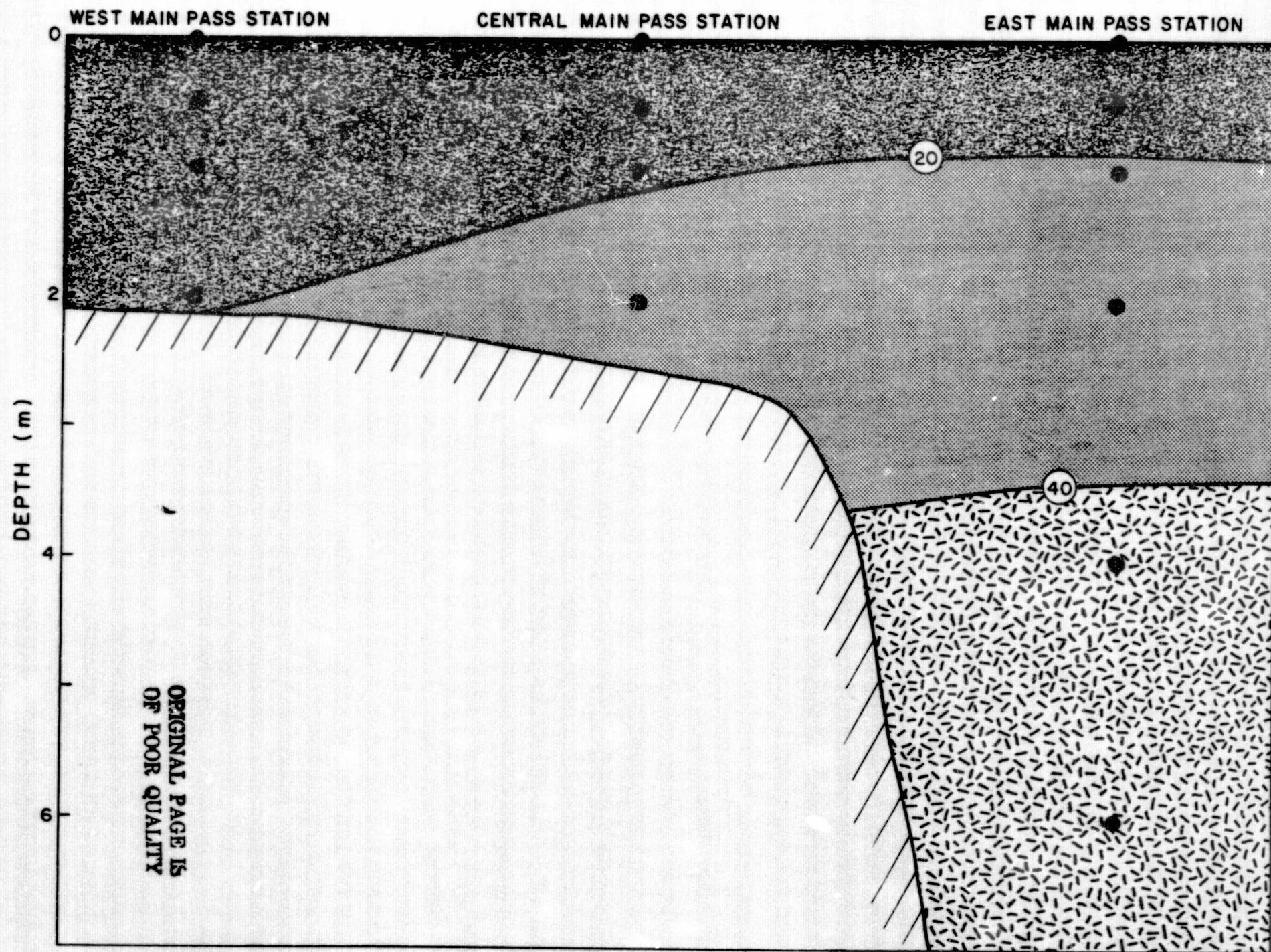
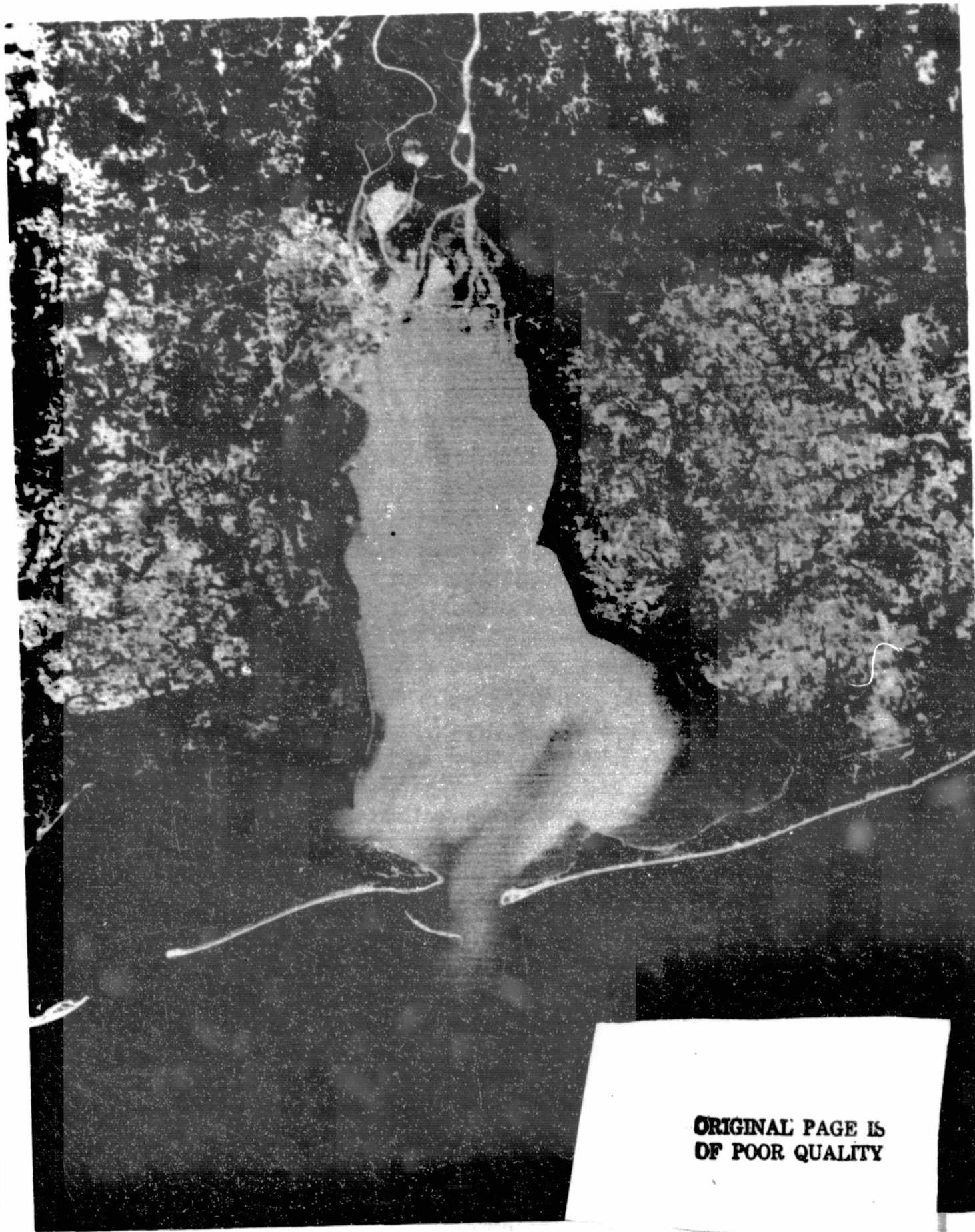


Figure 10.

**Figure 11. LandSat image (Scene ID number 2730-15310)
of Mobile Bay, January 21, 1977.**



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time and any attempt to approximate their inputs would only be misleading.

DISCUSSION

The most apparent fact discernible from the 3 cases is the striking synergism of the identified driving forces. The results of other efforts lead to this same fact. An excellent effort was made by Hardin et al (1976) to correlate LandSat-1 imagery with hydrologic conditions of river discharge and tidal prism but several obvious anomalies were unexplainable. It is highly likely that if the pre-existing wind regimes had also been considered a more complete picture would have developed. On the other hand Schroeder (1977) showed how large concentrations of SPM can be resuspended and transported out of Mobile Bay as a function of wind-wave action and tidal currents. However, no attempt was made to look at the contribution of the individual driving forces.

This information makes the requirement for wind and total energy input to the system all the more imperative if mass transport in Mobile Bay is ever to be quantified. It seems highly probable that any system or analytical scheme lacking this approach would fall far short of the real world.

This sediment loading/interaction information is badly needed in order to better assess the assimilative capacity of the bay system. Some guidelines must be developed to control the contribution of potentially harmful materials which may be directly or indirectly involved with the SPM.

DISSEMINATION OF PROGRAM RESULTS

The concept of "turbidity" was critically reviewed during a national conference held in 1974. The National Oceanographic Instrument Center had been charged with evaluating the current methodologies and quickly realized that few environmental parameters were more poorly understood, inconsistently mea-

sured or visibly obvious to the concerned citizen.

It was equally clear that optical measurements of particulate suspensions were popular and accurate if taken in the proper context but subject to considerable criticism and speculation if extended too far.

A major goal of the present study thus became an update of methodologies and philosophy involved in optical measurements of particles in water. One workshop was held in the early years of the continuing project and after much reflection it appears more useful to prepare the current bibliography as a guide to the scientific community entering this expanding field. Optical measurements have been included in the most recent efforts of the Bureau of Land Management on the continental alteration. It is to the many investigations developing these studies that this document is directed.

RECOMMENDATIONS

1) Mobile Bay SPM Budget

The following two year research effort is recommended for Mobile Bay in order to achieve an understanding of the interactions of the three main SPM system driving forces. (River discharge, tidal currents and wind-wave action).

Three stations, selected with considerations for both environmental needs and logistic problems, should be vertically sampled for SPM density (mg/l), light transmission (%T), salinity (ppt) and temperature ($^{\circ}\text{C}$). All three stations should be sampled on the same day, as close to synoptically as possible, on a repeating interval of every three to five days. The project should be carried out over no less than a one year period.

From this data base time periods can be identified when only individual forces (e.g. wind-wave action) were driving the system and periods when combinations of the forces (e.g. River discharge and tidal currents)

were driving the system. A summary of percent occurrence for each possible combination of the driving forces can then be produced. This will then allow for a ranking, in terms of most active to the least active, of the variables.

The second year's effort should concentrate on developing techniques to separate the effects of individual driving forces during periods of combined forces activity utilizing the highest ranked combinations determined during the first year. Considerable difficulty could arise if the most frequent occurrence involved all three variables. In this case it would perhaps be more constructive to use the highest ranked two-variable combination.

This research effort will not provide answers to all of the unknowns involved in formulating an SPM budget for Mobile Bay. But in the considered opinion of the present investigators that without the above research effort only a weak semi-quantitative understanding of Mobile Bays' SPM system is possible.

2) General SPM Budgets

The most elementary and possibly the most productive approach to both understanding and formulating SPM budgets would be to utilize environmental settings where only one or two of the three driving forces prevail, and where there is essentially a single uniform sediment type. Under these circumstances each of the driving forces could be properly qualified and quantified. Following this individual characterization, combinations of the driving forces could be studied in order to determine what occurs as a result of their interactions.

Even though the SPM budgets for each environmental setting will have

unique features, therefore precluding the practice of applying a single budget design across the board, the general information derived from these studies could serve as the much needed first order foundation data. In the final analysis it may very well be that only the simpler systems (i.e. symmetrical basin, single uniform sediment type and one, possibly two, driving forces) will ever be understood well enough that a practical working budget can be constructed.

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APPENDIX A

(FINAL NASA REPORT NAS8-30810 MAY, 1978)

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